



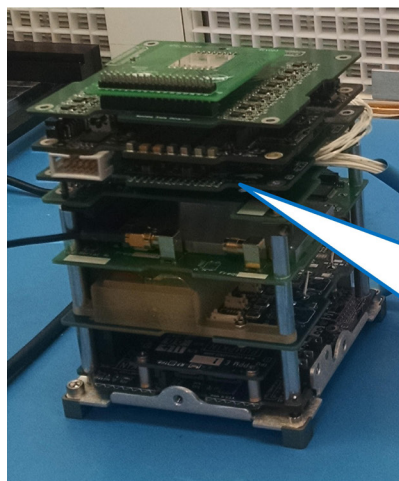
Radiation Tolerant, FPGA-based SmallSat Computer System

The Radiation Tolerant, FPGA-based SmallSat Computer System (RadSat) computing platform exploits a commercial off-the-shelf (COTS) Field Programmable Gate Array (FPGA) with real-time partial reconfiguration to provide increased performance, power efficiency and radiation tolerance at a fraction of the cost of existing radiation hardened computing solutions. This technology is ideal for small spacecraft that require state-of-the-art on-board processing in harsh radiation environments but where using radiation hardened processors is cost prohibitive.

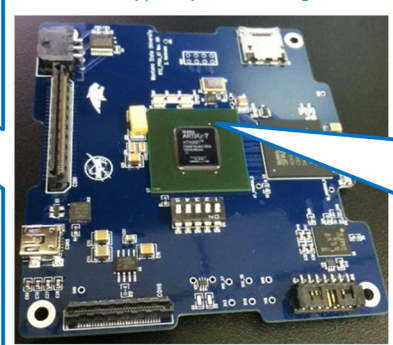
The technical readiness level of this computer system has steadily increased over the past eight years through a variety of tests and demonstrations including heavy ion bombardment in cyclotrons, nine high altitude balloon flights, and a sounding rocket flight to 62 miles (100 kilometers) in 2014. The computer technology has been selected by the NASA Flight Opportunities Program for a second sounding rocket flight to 93 miles (150 kilometers) in 2016. It has also been selected by the NASA Experimental Program to Stimulate Competitive Research (EPSCoR) program for a six-month demonstration on the International Space Station in 2016. Through the NASA SmallSat Technology Partnership

program, the computer technology is being integrated into a 3U CubeSat, a spacecraft measuring approximately 4 inches x 4 inches x 13 inches and weighing approximately 11 pounds (5 kilograms), for an orbital flight demonstration. This work has resulted in RadSat being selected by the 2015 CubeSat Launch Initiative for deployment through the NASA Educational Launch of Nanosats (ELaNa) program. The launch date is tentatively scheduled in the 2016-17 timeframe.

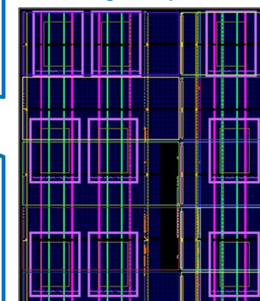
RadSat uses a novel fault mitigation strategy developed by Montana State University (MSU) that takes advantage of partial reconfiguration of modern COTS FPGAs. In this approach an FPGA is divided into redundant tiles, each with the characteristics that they can fully contain a computer system core and also be individually reprogrammed using partial reconfiguration. For the current RadSat implementation, each tile contains a Xilinx MicroBlaze soft processor. At any given time, three of the tiles run in triple modulo redundancy (TMR) with the rest of the tiles reserved as spares. The TMR voter is able to detect faults in the active triad by voting on the tile outputs. A configuration memory scrubber continually runs in the background and is able to detect faults in the configuration memory of both the active and inactive tiles. In the event of a fault in the active triad, (either



The processing core is based on a Xilinx Artix-7 FPGA that supports partial reconfiguration.



The FPGA is divided into partially reconfigurable tiles, each containing a soft processor.



The RadSat Computer Platform is Based on a Xilinx Artix-7 FPGA.

NASAfacts

detected by the TMR voter or scrubber), the damaged tile is replaced with a known good spare and foreground TMR operation continues. The damaged tile is repaired in the background by reinitializing its configuration memory through partial reconfiguration. This approach mitigates single event upsets (SEUs) in the FPGA circuit fabric in addition to single event functional interrupts (SEFIs) in the configuration memory. The advantage of this approach is that foreground operation can continue while the faulted tile is repaired and reintroduced into the system in the background, thus increasing system availability.

This approach has been implemented on an Artix-7 200T FPGA with 9 MicroBlaze soft processors. This 0.28um processor implementation has achieved a performance of 234 Million Instructions Per Second (MIPS) at 1 watt of power consumption. This represents a significant improvement in both performance and power efficiency compared to more widely adopted radiation hardened computer systems. The 0.28um process node inherently provides 500+ kilorad of Total Ionizing Dose (TID) immunity. The SEU/SEFI fault mitigation approach has been shown to provide a 90x improvement in mean time to failure (MTTF) compared to using Triple Modular Redundancy (TMR) with scrubbing alone on an equivalent process node.

The RadSat computer system is architected such that the fault mitigation procedures are abstracted from the developer. The computer system simply appears as a soft processor-based computer system with all of the flexibility inherent in implementing such a system on a programmable fabric. TID immunity is inherently provided through the 0.28um process node and SEE immunity is provided by the tile replacement procedure in the background.

RadSat directly contributes to multiple needs called out in the NASA Technology and Processing Roadmap. These include the need for *“ultra-reliable, radiation hardened platforms which, until recently, have been costly and limited in performance”* and *“innovative computing architectures to meet the needs of both science and engineering and emphasizes the need for scalable processing platforms that include intelligent fault-tolerant technologies to increase the robustness of computing platforms for long-duration missions.”*

The RadSat computing system has been developed at Montana State University in collaboration with the NASA Goddard Space Flight Center.

This project is funded through the SmallSat Technology

Partnerships, a program within the Small Spacecraft Technology Program (SSTP). The SSTP is chartered to develop and mature technologies to enhance and expand the capabilities of small spacecraft with a particular focus on communications, propulsion, pointing, power, and autonomous operations. The SSTP is one of nine programs within NASA's Space Technology Mission Directorate.

For more information about the SSTP, visit:

<http://www.nasa.gov/smallsats>

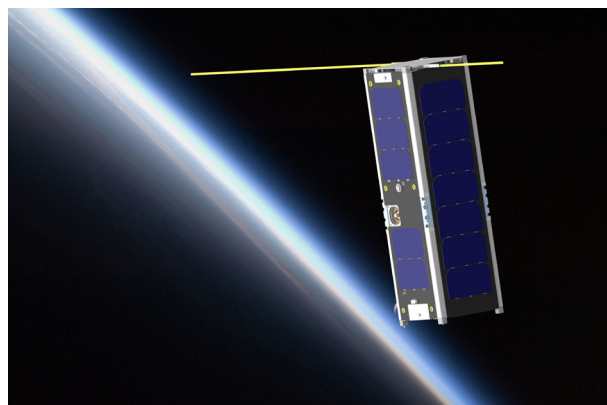
For more information about this project, contact:

Prof. Brock J. LaMeres
Electrical and Computer Engineering
Montana State University
lameres@ece.montana.edu

Gary A. Crum
Electrical and Computer Engineering Science Data
Processing Branch
NASA Goddard Space Flight Center
Gary.A.Crum@nasa.gov

Andres Martinez
Small Spacecraft Technology Program Manager
Space Technology Mission Directorate
NASA Ames Research Center
Andres.Martinez@nasa.gov

Andrew Petro
Small Spacecraft Technology Program Executive
Space Technology Mission Directorate
NASA Headquarters
Andrew.J.Petro@nasa.gov



RadSat will be deployed through the NASA CubeSat Launch Initiative as a 3U CubeSat. RadSat will leverage existing flight avionics that MSU has developed for the FIREBIRD-II satellite, which was deployed on ELaNa X.

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, CA 94035

www.nasa.gov

NASA Facts